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INFLUENCE OF PH AND BULK DENSITY ON CARBON DIOXIDE EFFLUX IN THREE URBAN WETLAND TYPES

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Abstract

The aim of this study was to understand soil carbon dioxide (CO_2) efflux of three different urban wetlands and how pH and bulk density relate to soil CO_2 efflux of each wetland. The three wetlands were bottomland, upland, and shrub/scrub. The study was conducted over a twenty week period using the Li-Cor 8100 “closed chamber” method to measure soil CO_2 efflux. The findings show that the bottomland wetland efflux was significantly higher than the shrub/scrub and upland wetland. The pH of shrub/scrub was significantly higher than the upland. The bulk density of the bottomland was significantly lower than the other two wetland types. There was no significant relationship between pH and CO_2 efflux, but there was a significant relationship between bulk density and CO_2 efflux. The contribution of the study is how understanding soil CO_2 efflux in urban wetlands can help to mitigate the effects of climate change.
Keywords: Wetland, Urban, Carbon Dioxide, pH, Bulk Density

Introduction

In 2011, the global population reached seven billion people. As the population continues to rise, ecosystems are faced with environmental pressures to maintain current levels of productivity. It is undeniable that wetlands are critical parts of the planet’s health. Wetlands are threatened ecosystems and are estimated to cover 6% of terrestrial land areas. Of that 6%, the United States is home to about 14% or 274 million acres of the world’s wetlands (Reddy and DeLaune, 2008). A mere 6% of the Earth is covered by wetlands such as swamps, marshes, river floodplains, and deltas. This meager 6% contains an estimated 350-535 gigatons of carbon (Mitra et al., 2005). Global climate change is one of the greatest threats to wetlands across the world because of the potential of land drying up and releasing massive quantities of carbon back into the atmosphere. In the event that atmospheric temperatures increase, this will likely result in a decrease of surface and ground waters because of evapotranspiration. Climate change has induced a greater need to protect the remaining wetlands while provoking innovative ways to construct new ones. The potential contribution of this study is an increased awareness of the importance of constructed and restored wetlands in combating global climate change.

To better comprehend the value of wetland performance in urban areas, the objectives of this study were to understand: (1) soil carbon dioxide (CO_2) efflux within three wetland types, (2) the effects of soil pH on soil CO_2 efflux, and (3) the effects of bulk density on soil CO_2 efflux. It was hypothesized that pH will have a significant effect on soil CO_2 efflux and that bulk density will also have a significant effect on soil CO_2 efflux.

Literature Review

One important component of wetlands that separates it from other terrestrial ecosystems is its soil. Wetlands are transitional lands between aquatic and terrestrial ecosystems where the water table is generally at or near the surface of the land. The definition of wetlands varies between agencies, but at the core there are three consistent themes: Wetlands must (1) predominately support hydrophytes, (2) have a hydric soil, and (3) have a saturated substrate or be covered during the growing season annually (Cowardin et al., 1979).

Wetlands serve as sources or sinks of carbon and, therefore, have a considerable impact on ecosystem productivity. Wetland productivity is dependent upon biomass accumulation, and of all terrestrial ecosystems wetlands have the highest carbon density (Kayranli et al., 2010). Wetland soils are carbon sinks due to prolonged anaerobic states and low microbial respiration rates. During times of anaerobic digestion, wetlands emit methane (CH4), which is a key source of carbon. Heterotrophic decomposition of organic matter and root respiration are the drivers of CO_2 production in soils.

Soil respiration or CO_2 efflux are two interchangeable terms that refer to the production of carbon dioxide in the soil. There are several factors that may influence soil CO_2 efflux. They are biotic (e.g., bacteria, fungi, algae, earthworms) and abiotic (e.g., soil pH, bulk density, pore space, moisture, temperature). The focus of this literature review is on pH and bulk density.

Soil pH is an abiotic factor that influences soil CO_2 efflux and is usually buffered from 6 and 7 in wetlands (Reddy and Delaune, 2008). Hall et al. (1997) observed that pH-value has an effect on soil CO_2 efflux. The investigation analyzed the relationship between plant growth, which contributes to root respiration, and denitrification potential. The relationship provided an estimation of denitrifiers populations size under elevated CO_2 conditions and soil pH. Other studies (e.g., Andersson and Nilsson, 2001; Sitaula et al., 1995) have also shown pH to have a significant effect on soil respiration. Adersson and Nilsson (2001) analyzed how dissolved organic carbon in mor humus was influenced by pH and the effects of pH on total microbial activity. It was shown that optimum pH for microbial growth was correlated with soil pH, and this is important when there are no other limiting factors such as water and temperature. Pandey et al. (2010) investigated factors influencing soil CO_2 efflux at forest and plantation sites. They reported that CO_2 efflux rates at both sites were significantly and positively correlated with pH. The efflux rates (mg CO_2 m^{-2} h^{-1}) varied between 102-320 and 99-543, respectively, for forest and plantation. The efflux differences were driven by other abiotic factors; in the forest soil temperature played a significant positive role while in the plantation soil temperature, and moisture were the drivers. In addition, Reth et al. (2005) used a non-steady-state-flow-through climate chamber to measure CO_2 efflux, and also confirmed the correlation between abiotic influences and soil CO_2 efflux. They found that soil temperature had a significant influence on CO_2 efflux with a percentage of variance ranging from 14-36%.

Bulk density is another abiotic factor that may influence soil CO_2 efflux. Soil surface interactions are estimated to return 28-70% of carbon to the atmosphere (Santruckova et al., 2010). Bulk density does not necessarily affect microbial activity directly, but drainage controls fundamental dynamics of CO_2 that improves efflux in the soil which yields higher available oxygen for microorganisms (Melling et al., 2005). Bauer et al. (2006) showed that in conventional tillage, CO_2 efflux had a negative correlation with bulk density and clay fractions. However, sand fractions were positively correlated with CO_2 efflux. The study showed that soil fractions had a role in the relationship. Bauer et al. (2006) found in sandy loam soil that bulk density and soil texture were related to CO_2 efflux when water contents were relatively high. Novara et al. (2012) investigated the effects of land cover and land-use changes on the ability to reduce CO_2

emissions. Soil bulk density was determined at 15 sites within the study at two different depths. This study revealed that soil organic carbon content in bulk soils had a significant negative linear relationship with CO_2 efflux. This showed that abiotic and physical properties have an important role to play in soil gas exchange.

Methods and Procedures

Study Area

The study area for this research is a 62.5 acre-site located in central East Baton Rouge Parish, Louisiana, adjacent to the Comite River. The Comite River serves as a westerly boundary line to the property. To the east of the property, Blackwater Road serves as the boundary line, while on the south side Hooper Road defines the boundary line. On the north side of the study area, residential development sets the boundary line of the property. The study area has three distinctive wetland types that consist of bottomland hardwood, upland hardwood, and shrub/scrub. The bottomland wetland portion of the study area originally was comprised of riparian forest. The soil in the bottomland contains sand as a remnant of a former soil mining operation. During the initial investigation of the area, the riparian zone was defined as a 300-feet vicinity adjacent to the Comite River on either side. This definition was based on the North American Mink Habitat Suitability Model (Allen, 1986). Following the initial destruction of the site, the remnant bottomland stand was located in the southwest corner while a more extensive stand was located on the north side of the property. The bottomland wetland presently extends from the southern boundary near Hooper Road to the northern residential boundary. From the Comite River, the bottomland wetland progresses eastwardly across the property to near center. According to the ecosystem restoration report, the typical tree species in this area include Sweetgum, Water Oak, American Elm, and Bald Cypress (Army Corps, 2000). The bottomland wetland area is transitioned by the presence of some upland hardwoods. Due to the topography of the conservation area, the upland portion is dryer than bottomland wetland and shrub/scrub. The shrub/scrub wetland portion of the study site starts from the center of the property and expands eastward to the boundary at Blackwater Road. The inlet overflow from the Comite River keeps the scrub/shrub soil moist to support the vegetation. The vegetation in this area include black willow, slash pine, wax myrtle, dewberry, cattail, plume grass, bluestem, softrush, and numerous other grasses, rushes, and sedges (Army Corps, 2000).

The study area is an abandoned soil mine, which was restored as types of wetlands. Prior to restoration, about half of the site had 8-15 feet of soil removed. The remaining portion of the site, after mining, consisted of moderately mature forested systems. During an investigation conducted by the Army Corps of Engineers, it was discovered that the mined areas were low in fertility and had a pH 5.4. The restored area includes 1.5 miles of walking trails and interpretive areas, and 10.5 acres of lakes, the southern and northern lakes, for aquatic recreations. The southern lake is 8 acres and the northern lake is 2.5 acres. Restoration planting in this area included: Loblolly Pine, Spruce Pine, Wax Myrtle, Bald Cypress, Tupelo Gum, Cherrybark Oak, Native Sweet Pecan, Blackgum, Willow Oak, Riverbirch, Cottonwood, Red Mulberry, Common Persimmon, Water Oak, Cow Oak, Live Oak, and Eastern Red Cedar (Army Corps, 2000).

Experimental Design

Stratified random sampling was used for the study. The study area was divided into three individual strata, the wetlands. These wetlands were bottomland hardwood (25 acres), upland hardwood wetlands (5 acres), and scrub/shrub (32 acres); they were broken up into experimental units. Each area was separated into relatively homogenous sections by using Light Detection and Ranging (LIDAR) to differentiate and distinguish the areas. The elevation, slope, and soil type were used to delineate the different wetland types. For each experimental unit, five random points were manufactured using ArchGIS. At each point, data were collected two times a week for twenty weeks, May 2, 2012 to September 27, 2012, using a LI-Cor 8100 Soil Gas Flux System.

Data Collection and Analysis

In this study, the soil CO_2 efflux system with a 20 cm closed-chamber was used to the measure soil respiration. The chamber uses a pressure/vacuum air flow system to adjust its collar position up or down. In addition, the chamber is designed with a pressure vent to control wind invasion and/or air seepage due to external and internal influences (Li-Cor, 2005). Soil respiration was measured two times a week over a twenty week period. PVC collars were placed in the field at least 24 hours before the first measurement was taken. The depths of the PVC collar varied but were not less than 6 cm deep. The collars were inserted until they had a solid foundation to maximize the reduction of lateral diffusion. Once the PVC collars were in place the 20 cm respiration chambers were placed on top of them to initiate the measurement sequence. An integrated pneumatic system permits the chamber to lower and close during measurements. This allows the minimization of mechanical disturbance while sensitive measurements are in progress. To prevent changes in the chamber, CO2 measurements were limited to two minutes. This action reduced the potential of underestimation from changes in soil-atmosphere concentration gradients (Davidson et al., 2002).

In preparation for soil sample collections, in the lab, 15 metal moisture containers were weighed and labeled. In addition to weighing the containers, the volume of a soil probe ring was measured. Once in the field, at each point (for the aforementioned random points) a soil sample was taken to be tested for soil pH, bulk density, and volumetric water content. The soil samples were taken within a one-foot radius of each point. To measure soil pH, separate soil samples were taken by using a small shovel within the same one-foot radius to the depth of six inches. The samples were placed in a plastic storage bag, labeled, and sealed for transport. In the lab, each of the soil samples was then unsealed and left to air dry for 48 hours before testing. Next, the soil was ground finely with a mortar and pestle. Once the soil was ground, 10 grams of each soil sample was measured and placed in a glass beaker. One milliliter of water was added to the soil to make solution mixture 1:1, or one part soil to one part of water. The solution mixture was mixed very well for three minutes before pH readings were taken. A Fisher Scientific AR60 pH/Ion Conductivity Meter/DO meter was used to measure the pH of the soils.

To measure bulk density, samples were collected by driving a soil core probe into the soil at a depth of three inches. When the probe ring reached its proper depth, the excess soil was removed by scraping the ring level with a flat blade knife. The samples were then stored in the previously weighed and labeled moisture containers for transport. Once back in the lab the canisters with the soil securely contained within were weighed to determine the wet weight of the soil. After the soils had been weighed, they were placed in a drying oven with the temperature set at 105ºC. The samples were dried for 24 hours. After removing the samples from the drying oven, each sample was weighed to determine the dry weight. For bulk density, the formula ($Db = M/V$) was used for calculations. For the volumetric water content, the equation ($\theta = mwet - mdry/Pw \cdot Vb$) was used. Soil CO_2 efflux was also measured the entire twenty weeks at each zone in all strata. The mean for each stratum was calculated at the end of the study period. Statistical analysis was performed by using SAS software. The statistical model used to determine the differences between group means was analysis of variance. In testing the analysis of variance, if the probability of the F-test was significant (i.e., $p < 0.05$) the means were compared using the TUKEY'S test. Correlation analysis between soil CO_2 efflux, pH, and bulk density were performed to assess relationships. To understand the relationship between CO_2 efflux and bulk density a linear regression was performed

Results

Soil pH

Figure 1 shows the pH levels of the different types of wetlands. The upland wetland had the lowest pH of the three areas studied, with a pH range of 6.04-6.08 and a mean of 6.064. The shrub/scrub wetland had the highest mean pH of 6.982, with a range of 6.01-7.51. The bottomland wetland mean pH level of 6.408 was in between those for the upland and shrub/scrub wetlands; its pH ranged from 6.1-6.8. The bottomland wetland was not significantly different from the pH levels of the upland and shrub/scrub wetlands. However, the shrub/scrub wetland's mean pH level was significantly different from the upland wetland's mean pH level.

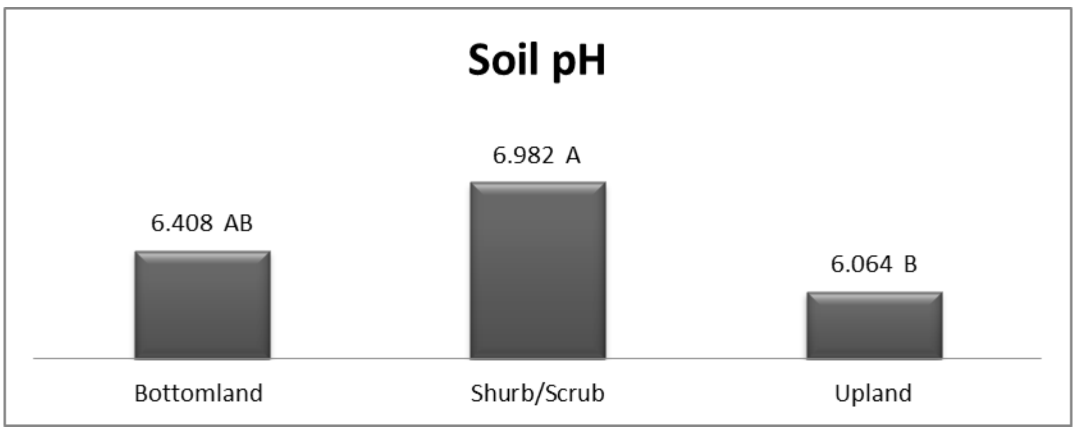

Figure 1. The distribution of soil pH levels of each wetland type measured in the Blackwater Conservation Area. The alphabets within the graph represent statistical differences between wetland types. The shrub/scrub wetland is significantly different from the upland wetland.

Soil Bulk Density

Figure 2 depicts the bulk densities of the three wetlands. The bottomland wetland had lowest mean soil bulk density at 1.10526 g/cm^3, with a range of 1.00477-1.28873. The upland wetland had the "medium" mean soil bulk density measuring 1.24651 g/cm^3, with a range of 1.1868-1.32514 g/cm^3. The shrub/scrub wetland had the highest soil mean bulk density of 1.32369 g/cm^3, with a range of 1.39795-1.20865 g/cm^3. The mean soil bulk density for the bottomland wetland was significantly different from the shrub/scrub and upland wetlands.

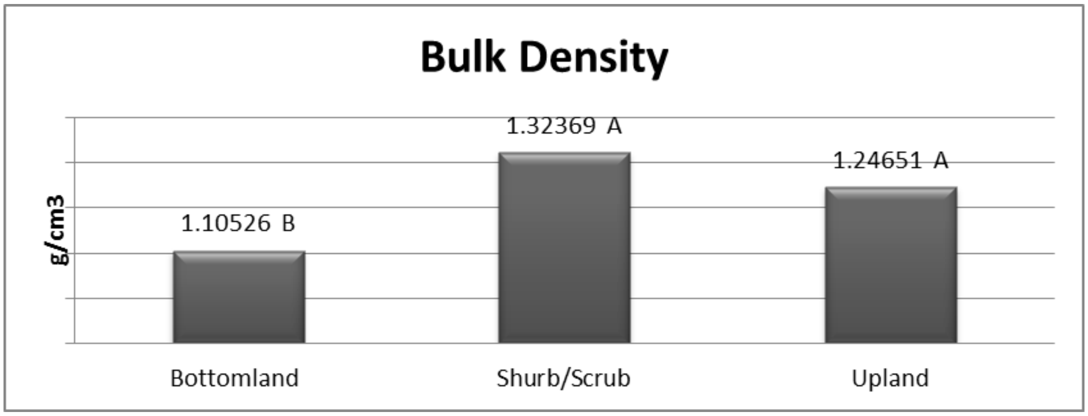

Figure 2. The soil bulk density of each wetland type measured within the Blackwater Conservation Area. The alphabets within the graph represent statistical differences between wetland type soil bulk densities. The bulk density in the bottomland wetland is significantly different from the other wetlands.

Soil CO_2 Efflux

Figure 3 presents the soil CO_2 efflux of the three wetlands. The shrub/scrub wetland had the lowest mean soil CO_2 efflux at 464.2 ppm. The "medium" mean CO_2 efflux was in the upland wetland measuring 467.3 ppm. The highest mean soil CO_2 efflux was found in the bottomland wetland measuring 497.5 ppm. The bottomland wetland mean soil CO_2 efflux was significantly different from the upland and shrub/scrub wetlands' soil CO_2 effluxes. There was no significant difference between the soil CO_2 efflux of the upland and shrub/scrub wetlands.

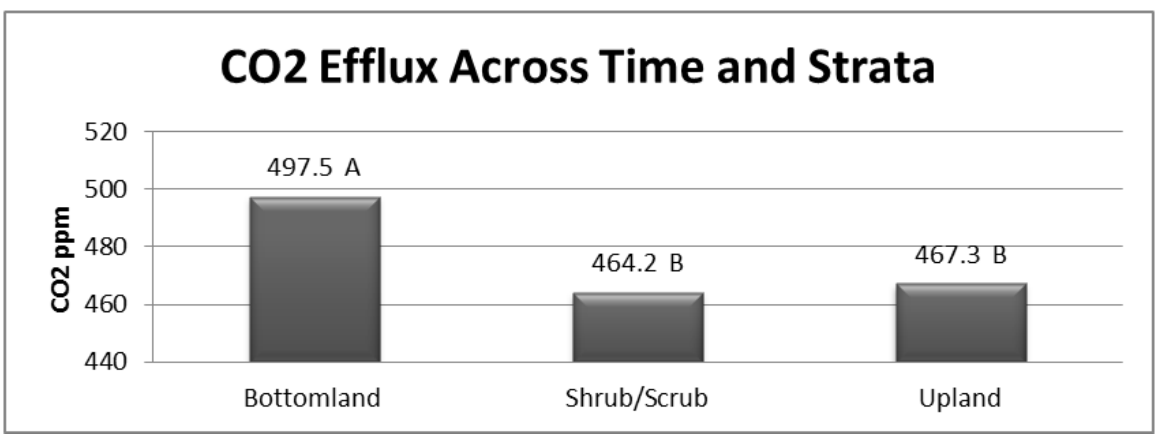

Figure 3. Soil CO_2 efflux measured within the three different wetland types over a twenty week period. The alphabets within the graph represent statistical differences between wetland types. The soil CO_2 efflux in the bottomland wetland is significantly different from the other two wetlands.

Discussion

pH Influence on CO_2 Efflux

It was hypothesized that pH will have a significant effect on soil CO_2 efflux. The results showed that there were no significant ($p > 0.05$) correlations of pH with soil CO_2 efflux (Table 1). This finding is different from what other studies have shown. For example, Reth et al. (2005) found that soil CO_2 emission correlated significantly with soil pH. Andersson and Nilsson (2001) and Hall et al. (1997) also reported that pH was significantly correlated with soil respiration. The differences in these studies may be because of factors like vegetation, pH-value of the soil, and other ecological influences facilitating the effects. Specifically, in the upland wetland, the lack of soil moisture could explain why pH influence was not significant.

Table 1. Results of Correlation Analysis between Soil CO_2 Efflux, pH, and Bulk Density

Factor	pH	Bulk Density
CO_2 Efflux	-0.176	-0.582*

*Correlation coefficient significant, $p < 0.05$

Bulk Density Influence on CO_2 Efflux

It was also hypothesized that bulk density will have a significant effect on soil CO_2 efflux. The results revealed that bulk density had a significant and negative effect ($p < 0.05$) on soil CO_2 efflux. This finding agrees with Novara et al. (2012) and Bauer et al. (2006). Novara et al. (2012) showed that bulk density exhibited a negative relationship with CO_2 emission. In addition, Bauer et al. (2006) found that bulk density in conventional tillage soils had a significant correlation with soil CO_2 efflux.

Figure 4 shows the regression results for soil bulk density and soil CO_2 efflux. It shows that as soil bulk density decreases, soil CO_2 efflux increases. This relationship may be related to soil with lower bulk density levels having a greater ability to exchange air with the atmosphere due its higher sand fraction. Thus, this would allow for a prevalent soil-atmosphere exchange of soil gases.

Conclusion

There are many environmental factors that affect respiration and soil gas exchange of CO_2. In this study, lower bulk density soils reached higher soil CO_2 efflux levels. From the results of this study, it appears that other environmental factors, such as soil moisture and temperature, have important roles in regulating soil CO_2 efflux. Although the shrub/scrub wetland had the highest bulk density, it had the lowest soil CO_2 efflux among the three wetlands. The upland wetland soil bulk density was similar to the shrub/scrub wetland. This suggests that topography and bulk density play an important role in drainage. This ultimately influences soil moisture, which is a

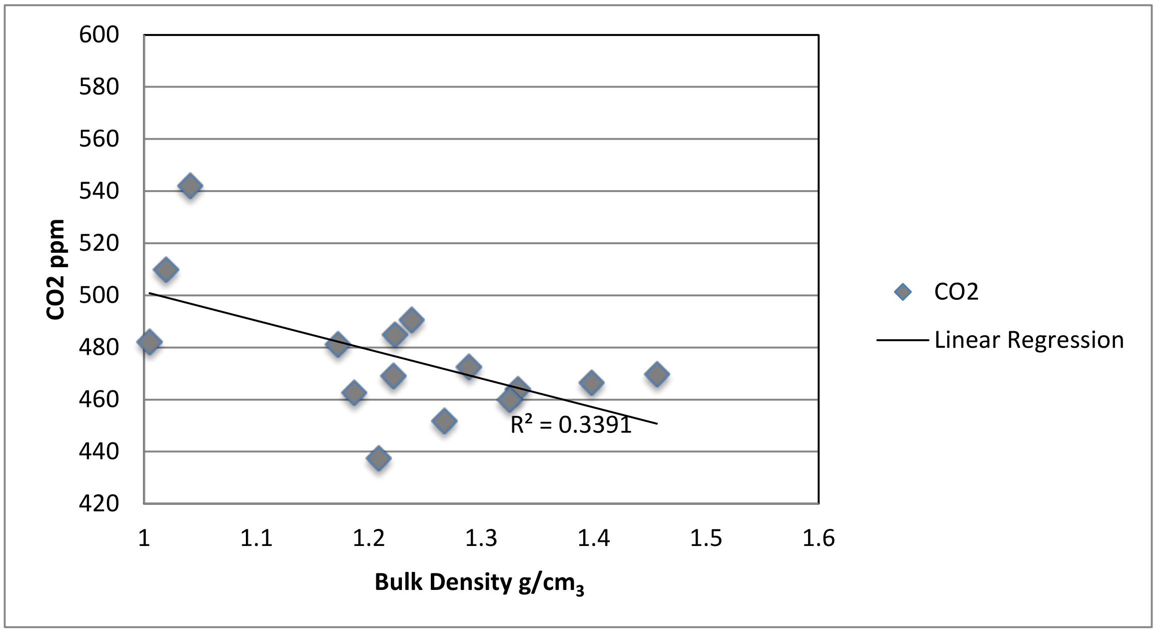

Figure 4. The relationship between soil bulk density and soil CO_2 efflux of the entire conservation area. Bulk density was the best single predictor variable of soil CO_2 efflux. Carbon Flux = 612 – (110.9 x bulk density).

regulator of soil CO_2 efflux. One of the limitations of this study is that soil fraction was not taken into account. The fraction of the soil would determine moisture to some degree. The other limitation was the constraint of time. Further investigation would be helpful to determine the effects of seasonal variations on soil CO_2 efflux. Better understanding the factors that influence soil CO_2 efflux in urban wetlands will potentially help planners and developers construct wetlands that aid in mitigating adverse climate change.

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